Processing indexical information demands resources:

Evidence from the change deafness paradigm.

By

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Processing indexical information demands resources:

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Abstract

Information about talker identity, referred to as indexical information, and the way it is processed in spoken word recognition is a topic of much debate. Current theories of spoken word recognition suggest indexical information is either removed entirely or encoded in its entirety. Recent research found that the amount of time spent processing the speech stream affects the amount of indexical information available to a listener. These effects suggest that the processing of indexical information is a resource demanding process. The current study uses the change deafness paradigm to examine both explicitly and implicitly the ability of participants to accurately detect a change between two speakers at the conclusion of an auditory lexical decision task. The results demonstrate that variable rates of processing affect the participants' ability to accurately detect a change in speaker, suggesting that the processing of indexical information is a resource demanding process.

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1. Introduction

1.1. Information available in the speech stream

Communication via spoken language is characterized by large amounts of information being conveyed in a relatively short period of time, and often in conditions that are less than ideal. The information that is available in the speech signal is typically classified into linguistic and indexical properties (Abercrombie, 1967). Linguistic properties in the signal provide information relevant to the message being conveyed. Indexical properties contain information about the speaker, such as sex, age, gender and emotional state. For example, when a man says the word “phone,” the linguistic information conveyed would be a “device used for auditory communication,” while the indexical information would include the fact the speaker is a man, his age, rate of speaking, mood, and amplitude..

1.2. Early views of indexical information

Originally this indexical information was believed to be superfluous in spoken word recognition. Because of this belief, Joos (1948) suggested that a process known as speaker normalization filtered out “phonologically irrelevant” speaker information (i.e. indexical information). This process was theorized because of the large amount of variability in the speech signal (McClelland & Elman, 1986; Marslen-Wilson and Warren 1994), such as length and shape of vocal tract, (Carrell, 1984), and positioning and control of articulators (Ladefoged, 1980). It was originally thought that it would be impossible to effectively process all these variables and the lexical information at the same time, making the process of speaker normalization necessary. Once this variability had been stripped away, the remaining abstract symbolic representation that remains is used for further linguistic analysis (Nygaard, Sommers, & Pisoni, 1995).

1.3. Speaker effects

In a series of experiments conducted at Bell Laboratories designed to investigate the way talkers are identified, an experiment was conducted to test the ability of listeners to identify a speaker in a time-reversed speech sample. During this experiment it was found that even with linguistic data being incomprehensible because of reversal of the sample, listeners were still able to identify the speakers significantly better than chance (Bricker and Pruzanksy, 1966).

The need to account for indexical information in the lexical representation created during spoken word recognition became evident when further research began to show speaker effects, facilitation or inhibition caused by variation in the speaker(s) of a stimulus, in several areas. An experiment was designed to test the effect of speaker's voice on same-different judgments using stimuli which differed by a single consonant or vowel phoneme. The stimuli selected for use were the sounds represented by the letters D, P, T, C, and A, E, O, U. The inter-stimulus interval (ISI) was also manipulated between 0.5, 2 or 8 seconds. It was found for both consonants and vowels that the reaction times for both same and different trials were significantly faster when the stimuli were produced by the same voice and that this effect of speaker interacted with ISI (Cole, Coltheart, & Allard, 1974).

These speaker effects were not limited to phonemic processing. Martin, Mullennix, Pisoni, and Summers (1989) investigated the role of indexical information in memory with three experiments using serial recall of word lists spoken with either one or multiple talkers. Ten item word lists were constructed of monosyllabic words spoken by either one speaker, ten speakers of the same gender, or five male speakers and five female speakers. In the first experiment no manipulations other than speaker variability were made and it was found that recall of early items from the single talker lists was better than the recall of early items from the multiple talker lists, suggesting that processing speaker variability requires more limited capacity resources in working memory than processing stimuli presented by a single voice. The second experiment used a preloaded digit recall manipulation using zero, three, or six digits. This manipulation was made in order to assess whether the rehearsal of items in working memory would be differentially effected by talker variability. The results from the experiment showed that processing talker variability requires more resources in working memory and this allocation of additional resources interferes with the rehearsal of items in working memory. Finally, the experimenters combined a retroactive interference task, lasting four, eight, or twelve seconds, with the recall experiment from experiment one. The results from the final experiment demonstrated that the length of the retention interval did not reliably affect the difference in recall of early list items between the two talker conditions. The overall conclusion from the experiment was that the results support the hypothesis that processing of words produced by multiple speakers requires more resources then those produced by a single speaker, demonstrating the effects of indexical information on lexical processing on memory.

Mullinnex, Pisoni and Martin (1989) manipulated speaker variability, lexical density, and sound-to-noise ratios in order to test the effects of talker variability in a perceptual task of spoken word recognition. The first experiment used a perceptual identification task, and their results demonstrated that talker variability produced significant interference in the perception of words degraded by noise. A follow-up experiment using a naming task with the same manipulations was conducted in order to test the effects of talker variability on perceptual processing time and the results from the first experiment were replicated. Further experiments used manipulations of word frequency and talker variability made to the same naming paradigm and these manipulations were both used in the second experiment. These results showed faster latencies for single talker conditions compared to the mixed talker conditions. The results from this series of experiments found that variation in talker's voice between trials produced significant interference on spoken word recognition, suggesting a mechanism that adjusts for differences in speakers' voices. Additionally the authors suggested that "talker variability is an important factor which must be considered in models of word recognition and lexical access and integrated into current theoretical descriptions (375)."

The necessity to include indexical information in lexical representations led to further experimentation to test the impact of speaker effects when the number of speakers varied. Palmeri, Goldinger, and Pisoni (1993) first used a continuous recognition memory task to assess the issue of the nature of the representation of voices in memory. Participants were presented with 2, 6, 12, or 20 speakers (half male and half female), and asked to judge if the stimulus they heard was new or old. This experiment yielded results in which the interference appeared to be an effect for introducing talker variability, but this effect did not increase with an increase in the number of the speakers. A second experiment was conducted using the same continuous recognition task; however, if the participants responded that the stimulus was old they were prompted to decide if it was presented in the same speaker's voice or a different speaker's voice than the first presentation. The results replicated the results from the first experiment, but did not show any additional affect on performance. Overall, the lack of differences in performance when the number of speakers is incrementally increased from two to twenty suggests that indexical information is not strategically encoded. For all of these experiments, if indexical information were truly stripped away during spoken word recognition, these effects would not have been observed.

1.4. Shared-resource approach to encoding of indexical information

The idea that the encoding of indexical information is automatic is not without opposition. Another approach to the encoding of indexical information is that the process involves constantly adjusting to the acoustic differences (Summerfield, 1975). When Mullinnex et al. (1989) examined the effects of talker variability on spoken word recognition, it was found that participants did worse when stimuli were presented by multiple speakers, which they argue showed a resource-demanding perceptual mechanism. They also found that these effects were increased when early acoustic information was disrupted, suggesting a close relationship between the early encoding of the auditory signal and the initial phonetic representation. These perceptual deficits were attributed to the competition for processing resources used by talker normalization processes and other perceptual processes.

Mullinnex and Pisoni (1990) further pursued the idea of a resource-demanding process in indexical encoding by examining the interactions between talker normalization and encoding processes, and the role of selective attention in normalization processes. To examine this relationship a modified speeded classification task was used where participants were asked to categorize either on speaker voice (2, 4, 8, or 16 voices, half of each gender) or consonant heard (/p/ or /b/). Results from the speeded classification task supported the hypothesis that encoding of voice information is required in speech perception (Fodor, 1983), and that these processes do not operate independently as demonstrated by the interference created by the inability to selectively ignore the other dimension in the speeded classification task. The effect of the interference increased in relation to the number of voices included during the task. This pattern of interference suggests that the processes for phonetic encoding and the encoding of indexical information share cognitive resources.

1.5 Time course effects on indexical processing

McLennan and Luce (2005) examined the hypothesis that indexical information requires time to influence spoken word processing. To accomplish this, three long-term repetition priming experiments were used, and reaction times of targets were measured that had been primed by a matched or mismatched prime on the desired indexical variable (either talker identity or speaking rate). The speed of processing was influenced by manipulating the phonemic probability of non-words used during the lexical decision task. High probability non-words take longer to process because there are many words phonotactically similar which causes interference when the non-word is processed, whereas low probability non-words are processed rapidly because they are phonotactically salient from words in the lexicon and this salience facilitates processing. The first experiment made use of a lexical decision task in the long-term priming paradigm and manipulated speaking rate. The results showed priming for both matched and mismatched primes, but these results varied significantly when the processing was slow and effortful. The second experiment made use of the same task and paradigm but manipulated talker identity. The results from this experiment followed the same pattern as Experiment 1, overall facilitation by the primes, but significant differences between fast and slow processing. A final experiment using a speeded shadowing task in the long term priming paradigm was conducted with the same manipulations for processing speed. These results showed that when processing was probed relatively late, indexical specificity effects emerged. All the results of the experiments suggest that lexical information is available early in the formation of the representation, but indexical information takes some time to be processed and affect the processing of spoken words.

1.6. Current Study

The current study was designed to test the effect of processing speed on the encoding of indexical information in spoken word recognition. This was accomplished by using the change deafness paradigm to test if participants were able to encode indexical information during the tasks. The change deafness paradigm tests the ability of a participant to detect an obvious change in speaker during an experiment (Vitevitch, 2003). It is expected that if encoding of indexical information is truly independent of processing time there should be no effect of processing speed on the availability of indexical information. But if the encoding of indexical information is dependent on the amount of time allowed for processing, as predicted, the anticipated results should show deficits in availability of indexical information when forced to process quickly compared to those processing less quickly. This difference manifests in the ability or inability of the participants to detect the change in the speaker.

2. Experiment 1

Experiment 1 tested whether the speakers selected for the following series of experiments could be differentiated easily. Clearly differentiated speakers were sought to rule out the possibility that participants in the following experiments simply could not tell the difference between the two speakers. In order to test this, a same-different task was implemented. If the speakers can be easily distinguished from one another, the accuracy rates in the same-different task will be high. However, if the participants are unable to distinguish between the two voices the accuracy rates would be low for the same-different task.

2.1. Methods

2.1.1 Participants

Twenty participants were recruited from General Psychology courses taught at the University of Kansas. Participants reported that they were native speakers of English and had no history of speech or hearing disorders. Compensation was given in the form of credit toward a course requirement for all participants. None of these participants took part in the subsequent experiments.

2.1.2 Stimuli

The stimuli consisted of 48 words that were highly familiar and had a high frequency of occurrence in the language, 48 high probability non-words, and 48 low probability non-words. All the stimuli were monosyllabic and had a Consonant-Vowel-Consonant (CVC) structure. The low probability non-words were selected from Vitevitch and Luce (1999; Appendix A). Originally fifty stimuli were selected for each category; however a duplicate in the high probability non-word group lead to the removal of the duplicate stimulus and a randomly selected item from both the words and low probability non-word groups. All stimuli were generated by two male speakers, whose fundamental frequencies were 130.03 and 125.40. An additional stimulus was removed at random from each category to facilitate ease of creation of stimuli lists for the experiment.

Four lists of 144 trials were created for this experiment. The stimuli were distributed randomly and evenly by group into either a change or same category. This led to the creation of seventy-two trials consisting of a stimulus followed by the same stimulus presented with the same speaker's voice (i.e. cat said by Speaker A twice), and the remaining seventy two trials consisted of a stimulus followed by the same stimulus, however spoken by the other speaker (i.e.

cat said by Speaker A then by Speaker B). The additional three lists were created in order to counterbalance for speaker and order.

2.1.3. Procedure

Participants were seated in front of an iMac running PsyScope (1. 2. 5 PPC), which was used to randomize and present stimuli as well as record responses. Participants were instructed that they would hear a stimulus immediately followed by the same stimulus over a set of headphones and should press the appropriately labeled button as quickly and accurately as possible to indicate whether both stimuli they heard were said by the same speaker or if they were said by a different speaker. A button box (New Micros) was used to collect responses.

Trials began with the word "Ready" appearing on the screen for 500ms, followed by the presentation of the stimulus over Beyer dynamic DT100 headphones at a comfortable listening level (approximately 65 db). The second word was presented 50 ms after the end of the first word. After the participant responded, the next trial began.

2.2. Results

The accuracy of participants' answers during the same-different task was measured to test for effective discrimination between the speakers' voices. Overall accuracy across the task, not specifically analyzing trials where the voices changed or stayed the same, gave a 95.6 percent accuracy rate. Analyzing trials specifically where the voice actually changed yielded 93.96 percent accuracy, clearly demonstrating that participants are able to effectively tell the difference between the two speakers selected for the following experiments using the changed deafness paradigm. When there was no change in speaker, participants were found to be accurate 97.92 percent of the time.

When analyzed by type of stimuli, accuracy for word stimuli was found to be 98.77 percent when the voices did not change and 94.27 percent when the voices changed. Non-words showed a similar pattern in both high probability and low probability conditions. High probability non-words elicited accuracies of 97.44 percent when the voices did not change and 93.75 percent when the voices did change. Low probability non-words showed almost identical results with 97.5 percent accuracy when the voices did not change and 93.75 percent accuracy when the voices did change.

2.3. Discussion

The data from this experiment was analyzed using only accuracy, as this experiment was designed only to test if the two speakers could be differentiated. As can be seen by the high accuracy, both overall and when the stimuli are separated by type, differentiation between speakers can be done accurately with both words and non-words. While accuracy decreased when the voice changed, the accuracy is still high. Additionally the same accuracy percentage for both high and low probability non-words in the changed condition suggest that type of non-word does not affect the ability of a participant to differentiate between speakers.

3. Experiment 2

Experiment 2 was conducted to test the hypothesis that processing of indexical information requires processing resources as suggested by Mullinex et al. (1989) and McLennan and Luce (2005). In order to test this, a lexical decision task making use of different types of non-words to facilitate different processing time durations was used. This manipulation is based on previous work conducted by McLennan, Luce and Charles-Luce (2003) in which investigation of direct access models and mediated models of lexical access were tested using flapped words. The successful use of high probability and low probability non-words in that work to encourage different depths or amounts of processing suggests that this manipulation is appropriate for the present experiment employing the change deafness task. If encoding of indexical information does not share processing resources, then the amount of time allowed for processing should have no effect on the encoding process, which would lead to no differences between the groups' ability to detect the change in speaker. However, if the encoding of indexical information is affected by the time allowed for processing, suggesting shared resources, there should be differences between the two groups' ability to detect the change in speaker. Specifically, listeners responding to high probability nonwords will process the stimuli (words and nonwords) to a greater extent than listeners responding to low probability nonwords, resulting in the high probability nonword listeners detecting the change in speaker more often than the low probability nonword listeners.

3.1. Methods

3.1.1. Participants

Forty-four participants from the same population that was sampled in Experiment 1 participated in this experiment. However, none of the participants that took part in Experiment 1 took part in Experiment 2.

3.1.2. Stimuli

Four lists of 98 stimuli were constructed for this experiment. Every list contained all 49 word stimuli, two lists contained the 49 low probability non-word stimuli and two lists contained the high probability non-word stimuli. The two lists containing similar non-words differed in that the first 49 stimuli were spoken by speaker A and the second 49 stimuli were spoken by speaker B. The second list had the first 49 stimuli spoken by speaker B, and the second 49 stimuli were spoken by speaker A. The different types of non-words were selected to facilitate different processing speeds. High probability non-words will take longer to process due to their word-like nature and as such will cause the words that are paired with them to be processed slower as well, while low probability non-words should be processed more rapidly due to their unword-like nature thereby facilitating more rapid lexical processing (Vitevitch & Luce, 1999).

3.1.3. Procedures

Participants were seated in front of an iMac running PsyScope (1.2.5. PPC), which was used to randomize and present stimuli as well as record responses. Participants were instructed that they would hear a sound over a set of headphones and should press the appropriately labeled button as quickly and accurately as possible to indicate whether what they heard was a real word in English or a non-word. A button box (New Micros) was used to collect responses.

Trials began with the word "Ready" appearing on the screen for 500ms, followed by the presentation of the stimulus over Beyer dynamic DT100 headphones (Frequency response 30 - 20,000 Hz, Ambient noise isolation 20 dB) at a comfortable listening level (approximately 65 db). After the participant responded, the next trial began. Halfway through the experiment (trial number 49) the voice of the speaker was changed to the other speaker. Upon completion of the lexical decision task participants were asked two questions by the experimenter:

(1) Did you notice anything unusual about the experiment?

(2) Was the voice in the first half of the experiment the same that was in the second half?

The answers were recorded on a new response sheet for each participant.

3.2. Results

Reaction times for the lexical decision task show that words paired with high probability non-words (M = 1029.94, SD= 180.51) were responded to significantly slower than words paired with low probability non-words (M = 947.71, SD = 1.2.67; $t(42)$= 1.77, p < 0.05 (one tailed)). This confirms that the words paired with low probability non-words are being processed more rapidly than the words paired with high probability non-words (McLennan, et al. 2003). Participants' answers to whether or not they detected the change in voice were analyzed using a chi-squared. Participants who had completed the lexical decision task with high probability non-words were significantly more likely to detect the change in speaker (86%) than those who completed the lexical decision task with low probability non-words (63%) (χ^2 = 3.93, p<0.05).

3.3. Discussion

The analysis of reaction times found that the manipulation of different probability non-words affected processing time as seen by the significant difference in reaction time. The significant difference in the chi-squared suggests that participants who received high probability non-words and therefore processed the stimuli longer had indexical information available to them more readily than those who received low probability non-words and processed more quickly. The ability to recall indexical information suggests that participants who process for a longer duration are better able to encode indexical information during spoken word perception than the participants who received low probability non-words. These findings suggest that the encoding of indexical information is a resource demanding process as suggested by Mullenix et al. (1989) and McLennan & Luce (2005), and may not be automatic as proposed by Goldinger (1998).

4. Experiment Three

Experiment 3 was conducted to test the recall of indexical information in a more implicit manner. To gather data a lexical decision task making use of different types of non-words to facilitate different processing time durations was used in conjunction with a rating task, asking the confidence of the participant that the voice did not change during the experiment. Rather than explicitly ask participants about the identity of the speakers as in the change deafness paradigm, the present task used an implicit test of the participant's ability to recall indexical information from the experiment.

4.1. Methods

4.1.1 Participants

36 participants from the same population that was sampled in Experiments 1 and 2 participated in this experiment. However, none of the participants that took part in Experiment 1 or 2 took part in Experiment 3.

4.1.2 Stimuli

The stimuli used in Experiment 2 were used in this experiment.

4.1.3 Procedure

The procedure for this experiment was similar to the procedure used in Experiment 2, with the following exceptions. First, the lists used in this experiment were the same as those in

Experiment 1; however, participants heard the same speaker throughout the entire experiment (i.e., the voices did not change). Second, instead of directly asking participants questions about a change in the voice as in Experiment 2, the participants were asked to rate:

> "On a scale from 1 to 10 (one being the least sure and ten being the most sure), how confident are you that the voice did not change during the experiment?"

The answers were recorded on a new response sheet for each participant.

4.2. Results

A total of five participants were removed from analysis for this experiment. In the high probability non-word condition three participants were removed for having accuracy below 75% on non-words, and an additional participant was removed for having a rating outside of two standard deviations of the mean. One participant was removed from the low probability non-word condition for having accuracy below 75% on non-words. Reaction times for the lexical decision task show that words paired with high probability non-words (M = 1170.34, SD = 173.43) were responded to significantly slower than words paired with low probability non-words (M = 1027.25 SD = 155.11; $t(29)$ = 2.42, p < 0.05 (one-tailed)). This again confirms that the words that are paired with low probability non-words are being processed more rapidly than the word paired high probability non-words (McLennan et al. 2003). The ratings given by the participants were analyzed and showed that participants given the high probability non-words (M = 7.5, SD = 2.03) were more confident that the speaker of the stimuli did not change than those participants who received the low probability non-words (M = 6.12, SD = 2.20; $t(29)$=1. 8, p<0.05).

4.3. Discussion

The results from this experiment support those results found in Experiment 2. Again the manipulation using different probability non-words had the desired effect of causing differing processing durations. More importantly, the rating task demonstrated the ability of participants receiving high probability non-words to say more confidently that the voice did not change during the experiment. This significantly higher confidence suggests, as in experiment 2, that those who are forced to process the stimuli for longer periods of time have access to indexical information; however, the significantly lower rating of those who received low probability non-words suggests a lack of (or an inability to retrieve) indexical information in the lexical representations created during spoken word recognition.

5. General Discussion

5.1. Effects of time course on indexical processing

While early models of spoken word recognition gave little credence to the importance of indexical information and focused largely on lexical information, the need to attend to such information arose after the demonstration of effects of talker variability on both spoken word processing and memory. The consistent presence and effect of indexical variables led some to believe that the processing of indexical information was required and automatic. Experiments by McLennan and Luce (2005) showed that indexical information was available if processing was effortful, but was unavailable if processing was speeded.

The current study used the change deafness paradigm to explore the availability of indexical information available to participants after the completion of a lexical decision task. The study implicitly and explicitly tested the participants' knowledge of this information by directly asking in the second experiment and the use of a rating task in the third experiment. Experiment 1 was designed to demonstrate that participants could effectively tell the difference between the two speakers designated for the following experiments based on speech perception. The high accuracy of participants in the same-different task showed that it was indeed possible to detect the difference between the two speakers.

Once this had been clearly established, use of the change deafness paradigm was implemented in a lexical decision task in experiment 2. The results from this experiment showed that those who received high probability non-words were able to detect the change in speaker better than those who received low probability non-words. The superior ability ($p < .05$) to detect the change in speaker by those who received high probability non-words is attributable to these participants having access to indexical information. Participants' impaired ability to detect the change while receiving low probability non-words suggests a lack of indexical information in the representations formed. The factor that can account for the use of different representations for high and low probability non-words would be the varying reaction times based on the type of non-words.

The results from the third experiment, in which participants were asked to rate their confidence that the voice of the speaker did not change during the experiment, supported the results found in the second experiment. Compared to the second experiment, where the participants were explicitly asked if the speaker changed, in the third experiment participants were asked implicitly whether or not the speaker changed. Participants who received high probability non-words had significantly higher ($p < .05$) confidence that the voice of the speaker did not change during the course of the experiment compared to those who had received low probability non-words. The significantly higher rating by those who received the high probability non-words supports the hypothesis that these individuals had access to indexical information, while those who received the low probability non-words had significantly less access to indexical information in the representation. The results from this study support the hypothesis that the amount of time spent processing will have an effect on the amount of indexical information available to the listener, where slow effortful processing leads to a lexical representation which contains more indexical information compared to those that do not.

5.2. Implications for spoken word recognition models

Current models of spoken word recognition favor an all or nothing approach to the processing of indexical information. Models such as TRACE (McLennand & Eldman, 1986) and Shortlist (Norris, 1994) use the speaker normalization process suggested by Joos (1948) and process only the lexical information present in a speech stream. The use of MINERVA 2, as suggested by Goldinger (2003), takes the opposite approach to indexical information and requires that it is processed automatically during spoken word recognition. Neither of these types of models can account for the results found in this study. The models of spoken word recognition which suggest that the indexical information is stripped away during the processing could not account for the ability of participants to detect a change in speaker, when the speed of processing was slowed by the use of high probability non-words. The MINERVA 2 model cannot account for the differences between the two conditions of low and high probability non-words; if indexical information were automatically encoded these differences should not have been found. These findings suggest that in addition to the inclusion of processing of indexical information to some models, accounting for the amount of time spent processing during spoken word recognition is also essential.

5.3 Future Research

The results from this study demonstrate the effect of differences in time spent processing information within the speech stream and the effects this can have on access to indexical information. It is inappropriate to assume that participants who received words paired with low probability non-words had no access to indexical information, only that less information was available. Future research will be aimed at deciphering if certain elements of indexical information (i.e. gender, F_0, mood, talker rate, amplitude) are lost due to speed of processing in a specific order, and, if so, what that order may be. This investigation is motivated by the idea that the importance of these variables in differentiating a speaker are different, and variables the system deems more important will be less susceptible to the effects of speed of processing.

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